https://doi.org/10.31713/m1021

THE ANALYSIS OF NATURE OF DAMAGE OF THE MATRIX MATERIAL, USED IN PRODUCTION OF DIAMOND DRILLING AND STONE-WORKING TOOLS DURING THE DESTRUCTION OF A ROCKS

Vynohradova O.P., Vasylchuk O.S., Zakora A.P., Petasyuk G.A. Garashchenko V.V.

N. Bakul Institute for Superhard Materials National Academy of Sciences of Ukraine,

Avtozavods'ka, 2, 04074, Kyiv, Ukraine, e-mail: vinelen@ro.ru

Abstract

In this paper are studied themechanism of matrix damage in rock cutting diamond toolswhen interacting with rock.

Earlier, in the sludge obtained during mining with a diamond tool on a block of sandstone of the Torez deposit, using a scanning electron microscope (SEM) ZEISS EVO 50 XVP, equipped with Oxford Instruments` Ultim Max 100 energy-dispersive X-ray analyzer (elemental analysis) particles were found whose chemical composition corresponded to the matrix material of the tool. According to the theory of M.V. Kirpichev, the complete correspondence of all configuration elements of the individual studied matrix particles and rock particles, which the sludge obtained as a result of work of diamond tool testifies to a single mechanism of brittle fracture of both counterbodies during dynamic interaction.

However, the nature of the matrix material indentation, remains, unexplored.

On the basis of the hypothesis that the damage to the matrix material of a diamond tool is carried out by roughness elements from the side of the rock, the goal was set to investigate the wear products of a diamond-free insert made from material, used as a matrix in a diamond rock-breaking tool with a short-term dynamic contact with cooling with a rock block

The originality of the method lies in the fact that in this study, the destructive indenters are not diamond grains, which gouge out particles of the rock, but elements of the roughness of the rock, which damage theexperimental cylindrical free-diamond element from NiSn (6%), having a density of 7.875 g/cm^3, performed by the method of intensive sintering.

The sludge obtained as a result of a short-term interaction of the experimental element and the rotating block of the rock on the bench was examined using a , using aabove-mentioned scanning electron microscope. The spectral analysis of the removed from the sludge particle of matrix material from which the experimental diamond-free element was made, confirmed the conformity of chemical composition of particle to the chemical composition of the matrix material of the experimental diamond-free sample.Full correspondence of all configurational components of a NiSn particle (6%) obtained by the action of a rock roughness element on a diamond-free insert during their dynamic interaction with all configurational components of wear particles of a diamond tool matrix., according to the similarity theory of M.V. Kirpichev, confirms the above-mentioned hypothesis.

Key words: rock cutting diamond cutting tool, matrix, damage mechanism, matrix material particle, sludge, scanning electron microscope

Introduction

One of the main criteria when choosing the chemical composition of a diamond-containing matrix for a rock-destroying tool is the conformity of the wear resistance of the matrix to the abrasive properties of the rock.

The loss of mass of the matrix material of the drilling tool, according to works [1,2] occurs due to the simultaneous indentation of spherical particles of rock sludge, resulting in scratches on the working surface of the matrix. A similar effect of abrasive particles on existing cracks and dislocations in the metal counterbody is indicated in [3-8], and the directions of crack propagation, as the authors indicate, ultimately affect the shape of the separated particle of destruction products of the metal sample, i.e,its wear is represented by a chaotic process.

A generally accepted measure of the wear rate of functional elements of drilling tools for diamond-containing composite materials (CDM) is to measure the loss of the mass or linear dimensions, which does not reflect the mechanism of the wear of the composite material.

The efficiency of the diamond drilling tool with a high wear-resistance depends from detailed study of the mechanism of interaction of a single destructive diamond indenter with a rock

It is on the basis of the above conclusions after studying of the granulometric composition of the sludge created a model of the damage to the diamond-bearing matrix in accordance with the work of Isonkin O.M. [9] thanks to simultaneous indentation of spherical rock particles into the matrix surface, as a result, on the working surface of the matrix of the drill bit (hardness on the HRC-15 scale,), equipped with synthetic diamonds, there were scratches.

The destruction of the matrix of rock-destroying elements of the drilling tool, according to [10] is similar to the destruction of the bottom after the work of the rock -brearing tool - with formation of microgrooves on the working surface of the matrix in the form of a series of microholes, alternating with a variable step and the width –*a*, Fig.1 when chipping the products of destruction in the form of microparticles of of diamond-containing matrix of hard alloy, chipped from the element of "Slavutych" during the destruction of sandstone of the Torez deposit, Fig. 2, characterized by all components of the geometric parameters of a single particle of rock sludge: the zone of indentation 1, lateral parts 2 and the final part 3, Fig. 2,3 [11].

It is determined that the chemical composition of the particles in the selected by method of magnetic separation, the magnetic fraction of sludge (from products of destruction obtained after the turning the core of sandstone of Torez field with a cylindrical diamond rock-breaking element, corresponds to its matrix material from NiSn (6%) [12].Their geometrical parameters are similar to the geometric parameters of particles of destruction of rock, which testifies to the fragile nature of the wear of the specified matrix material

Національний університет
водного господарства
та природокористування

a *b*

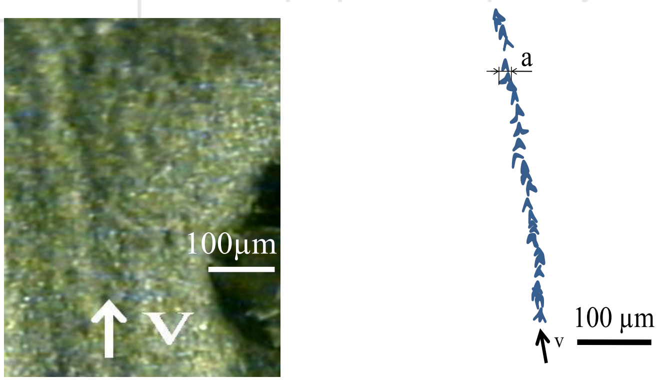


Fig. 1. The general view of: the working surface of the tungsten-cobalt matrix of the diamond rock-breaking element - *a*; *v*– the vector of the speed of breaking off of micro-particles of a matrix; schematic representation of a micro-groove consisting of microholes of hard alloy on the surface of the matrix, - *b*; *a* – the width of the microhole

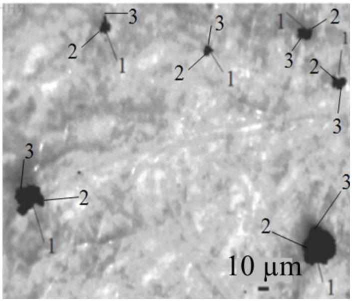


Fig. 2. The particles of fracture products of diamond-containing matrix of hard alloy, chipped from the element of "Slavutych" during the destruction of sandstone of the Torez deposit, *1* - zone of indentation (by sharp edge of quartz grain); *2* - lateral part; *3* - final part

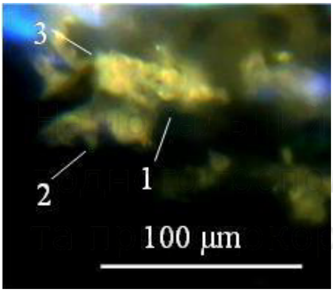


Fig. 3. The particles of sludge, chipped off from the block of sandstone of Torez field with a thickness of 40 µm: *1* - indenter penetration zone; *2*– lateral par; *3*– final part

However, the mechanism of fracture of the surface layer of the composite diamond material has not yet determined**.**

The purpose is to study of the nature of damage to the surface of a diamond-free element from NiSn (6%) by the block of sandstone of Torez field at dynamic loading.

Research methodology.

The tests to determine the nature of damage to the matrix material of experimental drilling diamond-containing elements were performed by the interaction of cylindrical block of sandstone of the Torez deposit of drilling category IX and the cylindrical free-diamond elementfrom NiSn (6%), on a special stand created on the basis of a lathe model DIP-200.The method of work on aspecial stand created on the basis of a lathe model DIP-200.is described in detail in [13].

Before the start of the tests, a core of sandstone with a diameter of 93 mm and a length of 400 mm 1, fig.1, was drilled with a 112 mm diameter by drill bitand fixed incore holders 2 of a lathe. Cooled by the cooling system 3, the the cylindrical free-diamond element 4, fixed in a tool holder of a lathe and brought to the surface of the rock core, where longitudinal destruction of the cylindrical free-diamond element was carried out. The sludge 5 accumulated in the sludge collection bath 6 and moved through a hose for discharge of sludge 7 into the sludge receiver.

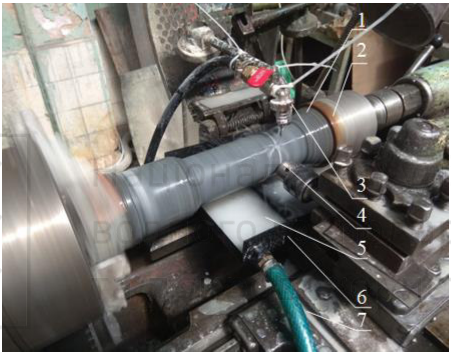


Fig. 4 The general view of a special stand in the process of research: *1* - cylindrical block of sandstone of Torez deposit; *2* - core holder; 3 - cooling system of cylindrical free-diamond element *4* - cylindrical free-diamond element; *5* - sludge; *6* - sludge collection bath; *7* - hose for discharge of sludge into the sludge receiver

The experimental cylindrical free-diamond element from NiSn (6%), having a density of 7.875 g/cm^3, was performed by the method of intensive sintering under the condition of simultaneous pressing: pressure - 300 MPa, sintering time - 14 sec amperage -1.3 kA.

The surfaces of diamond-free insertwas examined with a Bausch & Lomb, mod. Gemolite, microscope.

The sludge, in the form of a suspension, was selected, dried and examined on a microscope of the DiaInspect OSM device from VOLLSTADT DIAMANT GmbH DiaInspect OSM in order to separate rock particles and particles of the insert material, chipped off from its working surface during the dynamic action of sharp roughness elements of a rock block. The method of work on a microscope of the DiaInspect OSM device from VOLLSTADT DIAMANT GmbH DiaInspect OSM is described in detail in [14].

Besides,at the final stage of research, the dried sludge was examined by scanning electron microscope (SEM) ZEISS EVO 50 XVP, equipped with Oxford Instruments` Ultim Max 100 energy-dispersive X-ray analyzer (elemental analysis).

Results

As a result of the short (1 min) interaction of the cylindrical element at turning with the surface of the pre-prepared by diamond tool abrasive sandstone core, at a feed rate of 0.148 mm / rev, at a feed rate of washing liquid of 5 l/min,the surface of the insert was examined with a Bausch & Lomb, mod. Gemolite microscope.

On the surface of the insert, micro-grooves were found, fig. 5*a*, identical to those formed on the surface of inserts equipped with diamond grains, that is, damage to the matrix surface occurred in both cases by roughness elements from the side of the rock block. The geometrical parameters of microholes on the surface of a free-diamond insert and microholes on the surface of inserts made of composite diamond-containing materials were identical. The width of the microholes, fig. 5*b*, reached 400 µm and the average width of the microholes creating micro-grooves 3 on the insert surface reached 200 µm.

a *b*

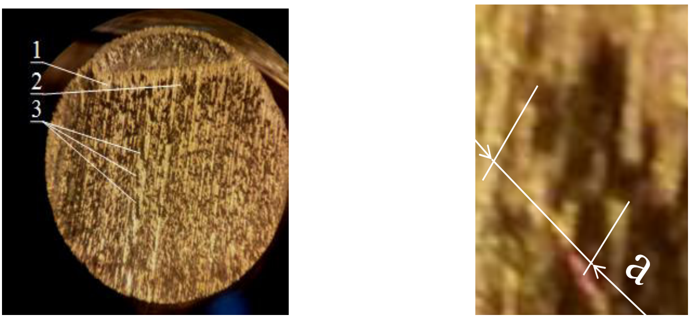


Fig. 5. The general view:ofthe surfaces of diamond-free insert: *1* - intact surface of the insert; *2* - microhole; *3* - microgrooves on the surface of insert-a, microhole 2 in Fig.5*a* (enlarged), *a* - width of microhole–*b*

The sludge, in the form of a suspension, was selected, dried and examined on a microscope of the DiaInspect OSM device from VOLLSTADT DIAMANT GmbH .

The sludge samples were examined in the field of view of a microscope of the DiaInspect OSM device from VOLLSTADT DIAMANT GmbH with penetrating lower light flux and upper illumination from a halogen light source,where the particles of sludge were located, consisting of particles of rock and the material of the insert, so, two types of particles were found, Fig. 6.

The particles of rock and, hypothetically, particles from material of the insert in the field of view look as particles light coloured and black–particles of a rock and particles of material of the experimental cylindrical free-diamond element,respectively.

An important feature of the geometric parameters of the presented particles is the presence of all the features of the configuration of rock particles when it is destroyed by a diamond tool and particles of a matrix material when a diamond-containing tool is damaged,namely, the zone of indentation (by sharp edge of quartz grain) – *1*, lateralpart – *2*, final part – *3*

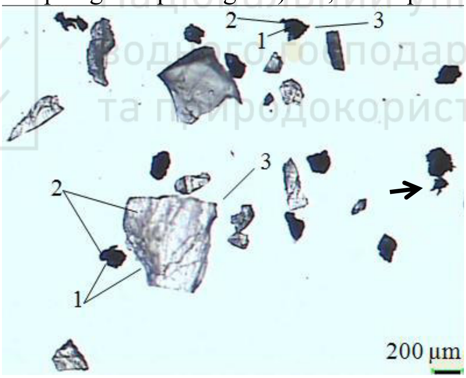


Fig.6. The particles of rock and, hypothetically. the particles of the material of the diamond-free insert in the field of view of a microscope of the DiaInspect OSM device from VOLLSTADT DIAMANT GmbH with penetrating lower light flux and upper illumination from a halogen light source: light coloured particles – particles of a rock, black particles–hypothetically, the particles of material of the experimental cylindrical free-diamond element: *1* - the zone of indentation (sharp edge of quartz grain); *2* –lateral part; *3* – final part – *b*

In order to make sure that the black particles on the microscope table are the particles of the insert material, a spectral analysis of the particles was carried out.

The dried sludge was examined by scanning electron microscope (SEM) ZEISS EVO 50 XVP, equipped with Oxford Instruments` Ultim Max 100 energy-dispersive X-ray analyzer (elemental analysis).

The study of the sludge fraction using a SEM, shows that thechemical composition of some particles, for example, presented on Fig. 7*a*, coincides with the composition of the material of the experimental element from NiSn (6%), Table 1,2 which is diamond-free.

The particle is located on the particles of the rock, as evidenced by the chemical compositions of the spectra №№ 45,46,47 with the predominant values of Silicon and Oxygen.

When moving, schematically, the detached end part 2', Fig.7*b* to the main lateral part 2, the particle take on a finished form.

The zone of penetration 1 of the particle is formed together with the residual zone of penetration 1', which, when chipping off the particles of rock with a diamond tool, is formed extremely rarely, is lost due to high fragility. With an increase in plasticity, as in the case of the studied matrix material, the residual zone 1'may not be destroyed.

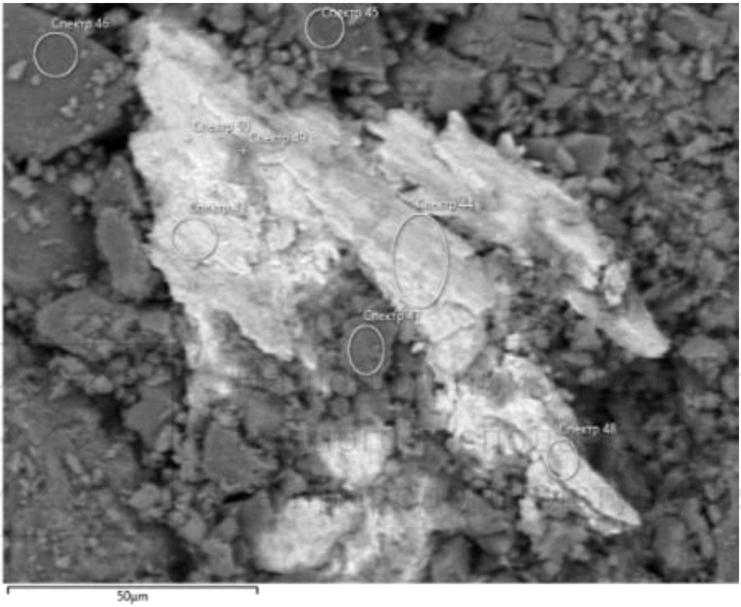
The particle have an axis of symmetry; moreover,all geometrical parameters, inparticular, the introduction zone 1, the lateral parts 2, end zone 3, Fig. 6*b*, as well as overall dimensions, correspond to the relevant parameters of the particles of the wear of the element from the composite diamond-bearing material under similar conditions of their working off [12].

The geometric parameters of the particle, its overall dimensions (width and length– nearly, 90 and 150 μm, respectively), the configuration are correspond to the corresponding parameters of the particles of the matrix material, studied in the field of view of a microscope of the DiaInspect OSM device from VOLLSTADT DIAMANT GmbH with penetrating lower light flux and upper illumination from a halogen light source.

In the particle, shown by the arrow in Fig. 6, residual zone of penetration is saved. Therefore, there is reason to believe that black particles in the field of view of a microscope of the DiaInspect OSM device from VOLLSTADT DIAMANT GmbH with penetrating lower light flux and upper illumination from a halogen light source are particles of the matrix material.

Unfortunately, the particle thickness remains undetectable for the time being.

a



b

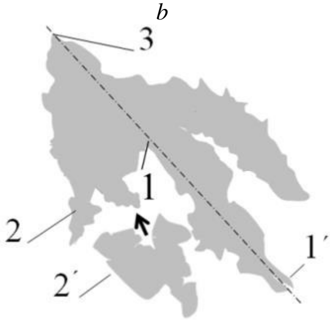


Fig. 7. The general view of the particle of wear of the diamond-free element fom NiSn (6%), against the background of abrasive sandstone sludg eparticles– image received by spectral analysis–a, schematic image of the zone of penetration 1 of the particle, residual zone of penetration 1', the main lateral part 2, the detached lateral part 2 ', final part 3–*b*

The table 1 shows, that the spectra №№43,44, 48,50 are with a predominance of Nickel in the background of sandstone particles.

The chemical composition of the sludge particle in spectrum №. 44, shown in Fig. 8, represented in Fig. 6a, in the center of the particle, namely, in the zone of indenter penetration 1 from the side of the rockby roughness element indicates on content, in addition to 71.37% Nickel , 5.42% - Stanum, which is as close as possible to the content of Stanum in the bundle - 6%, Table 1,2.

In the Spectra 50 composition, the maximum Nickel content is 84.08%, and the Stanum content is 3.74%.

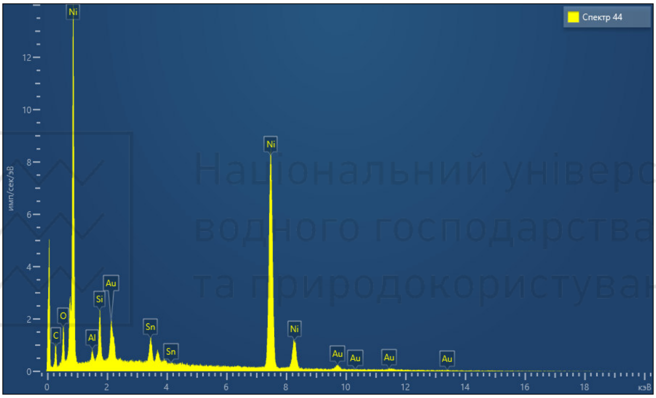


Fig. 8. The chemical composition of the sludge particle obtained by the interaction of the diamond-free experimental element with NiSn (6%) with the sandstone core of the Torez deposit, according to the results of spectral analysis - spectrum № 44

Table 1

The chemical composition of the sludge according to the results of spectral analysis

Sperc-ter tag	Spectrum 43	Spectrum 44	Spectrum 45	Spectrum 46	Spectrum 47	Spectrum 48	Spectrum 49	Spectrum 50
C	12.33	12.88	9.66	12.51	11.26	12.55	10.91	11.30
O	3.61	5.90	52.81	31.33	49.51	8.29	28.55	
Al	0.77	0.98	0.21		0.37	0.88	0.83	0.60
Si	1.78	3.46	36.73	56.15	37.20	4.80	25.05	0.29
Ni	77.06	71.37	0.57		1.65	68.73	33.07	84.08
Sn	4.45	5.42				4.75	1.58	3.74
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Result type-weight,%

Table 2

Statistics data of he chemical composition of the sludge according to the results of spectral analysis

Statistics	C	O	Al	Si	Ni	Sn
Max	12.88	52.81	0.98	56.15	84.08	5.42
Min	9.66	3.61	0.21	0.29	0.57	1.58
Average	11.68			20.68		
Standard deviation	1.09			21.15		

Conclusions

1. The working surface of the diamond-free experimental element is completely covered with a system of micro grooves formed by fixed indentation quartz in the form of roughness elements of the rock block.

2. Each micro-groove on the working surface of the experimental insert is formed from, separately, chipped single microholls, which indicates the fragile nature of wear of the diamond-free experimental element.

3. Geometrical parameters of a separate microholl on the surface of the diamond-free element (configuration and dimensions which reaching 400-500 μm) and micro-holes on the surface of the diamond-containing rock-destroying element based on a matrix from NiS n(6%) are identical.

4. Spectral analysis of the removed from the sludge particle of matrix material from which the experimental diamond-free element was made, which was subjected to dynamic loading from the rock block, confirmed the conformity of chemical composition of particle to the chemical composition of the matrix material of the experimental diamond-free sample.

5. The above statements confirm the hypothesis that the mechanism of wear of the matrix material of diamond-bearing rock-destroying tool consists in indentation in the surface of the matrix by "fixed" elements of rock roughness, followed by detachment from the matrix surface of individual particles of matrix material.

6. The configuration of wear particles of the matrix material of diamond rock-destroying tool, diamond-free element based on the same matrix material and particles of rock destruction is identical, which indicates the fragile nature of rock fracture and matrix from

these chemical elements,i.e.in the process of rock destruction there is mutual destruction: diamond grains in the tool chip off single particles of rock, and its elements of roughness destroy the matrix material of the tool.

7. Determination of the source of damage to the working surface of a diamond-containing rock cutting tool during rock destruction opens up new prospects in the study of the wear mechanism of the matrix material and makes it possible to develop criteria for the wear resistance of drilling and stone-working tools, which is reflected in the resource saving of the matrix material.

8. Full correspondence of all configurational components of a NiSn particle (6%) obtained by the action of a rock roughness element on a diamond-free insert during their dynamic interaction with all configurational components of wear particles of a diamond tool matrix. , according to the similarity theory of Kirpichev [14], confirms the hypothesis [15,16] that one of the sources of damage to the matrix material is the damage to the matrix material of the diamond-containing mining cutting tool occurs by fixed roughness elements from the side of the rock.

Reference

1. **Isonkin, A. M.** (2010). Kharakter i stepen vozdeisviia chastits shlama razrushennoi hornoi porody na matritsu almaznoi burovoi koronki [The character and degree of the impact of sludge particles of destroyed rock on the matrix of diamond bit]. Porodorazrushaiushchii i metalloobrabatyvaiushchii instrument – tekhnika i tekhnolohiia eho izhotovleniia i primeneniia [Rock Destruction and Metal-Working Tools –Techniques and Technology of the Tool Manufacture and applications] Vol.13, 182-187 [in Russian].

2. **Isonkin, A. M., Ilnitskaia, H. D., Tsysar, M. A.** (2015). Vliianiie mekhanoaktivirovaniia shikhty WC+Co+Cu nanoalmazami na strukturu i svoistva materiala matritsy burovykh koronok. [The effect of mechanical activation of the charge WC + Co + Cu by nanodiamonds on the structure and properties of the material of the matrix of drilling bits]. Porodorazrushaiushchii i metalloobrabatyvaiushchii instrument – tekhnika i tekhnolohiia eho izhotovleniia i primeneniia [Rock Destruction and Metal-Working Tools –Techniques and Technology of the Tool Manufacture and applications] [Rock Destruction and Metal-Working Tools –Techniques and Technology of the Tool Manufacture and applications], Vol.18, 103-109 [in Russian].

3. **Netrebko, V.V.** (2019). Naukovi ta tekhnichni osnovy pidvyshchennia mekhanichnykh i sluzhbovykh vlastyvostei vysokokhromnykh chavuniv [Scientific and technical bases of increase of mechanical and service properties of high-chromium cast iron]. Extended abstract of Doctor'sthesis. Zaporizhzhia [in Ukrainian].

4. **Chepovetskii, I.Kh.** (1978). Mekhanika kontaktnoho vzaimodeistviia pri almaznoi obrabotke [Mechanics of contact interaction in diamond processing]. Kiev: Naukova dumka [in Russian].

5. **Ohlezneva, S.A.** (2004). Almaznyi instrument s fazovymi prevrashcheniiami [Diamond tools with the phase transformations]. Treniieiiznos – Friction and wear, Vol. 25, 1, 79–84 [in Russian].

6. Zybinskii, P.V., Bogdanov, R.K., Zakora, A.P., &Isonkin, A.M. (2007). Sverkhtverdyie materialy v geologorazvedochnom burenii [Superhard materials in exploration drilling]. Donetsk: Nord-press [in Russian].

7. **Soloviev, N. V., Chikhotkin, V. F., Bogdanov, R. K., & Zakora, A. P**. (1997). Resursosberehaiushchaia tekhnolohiia almaznoho bureniia v slozhnykh heolohicheskikh usloviiakh [Resource-saving technology of diamond drilling indifficult geological conditions].Moscow: VNIIOENG [in Russian].

8. **Gorshkov, L,.K., Iakovlev, A.A., Pavlov, N.A.** (2010). Matematiko-mekhanicheskaia model razrusheniia porod pri burenii [Mathematical and mechanical model of rock destruction during drilling]. Porodorazrushaiushchii i metalloobrabatyvaiushchii instrument - tekhnika i tekhnologiia ego izgotovleniia i primeneniia [Rock-cutting and metal-working tools - equipment and technology for their manufacture and use], Vol. 13, pp. 3-7. [in Russian].

9. **Isonkin, A. M.** (2012). Formirovaniie reliefa rabochei poverkhnosti almaznoi burovoi koronki. [The formation of the relief of the working surface of the diamond drill bit]. [Rock Destruction and Metal-Working Tools – Porodorazrushaiushchii i metalloobrabatyvaiushchii instrument - tekhnika i tekhnolohiia eho izhotovleniia i primeneniia [Rock Destruction and Metal-Working Tools –Techniques and Technology of the Tool Manufacture and applications] , Vol. 15, 63–68 [in Russian].

10. **Vynohradova, O.P., Shmehera, R.S., Suprun, M.V.** (2016). Doslidzhennia kharakteru ruinuvannia almazovmisnoi matrytsi burovoho instrumentu pry zminiy ii khimichnoho skladu [Investigation of the nature of the destruction of the diamond-bearing matrix of the drilling tool by changing its chemical composition].– Porodorazrushaiushchii i metalloobrabatyvaiushchii instrument – tekhnika i tekhnolohiia eho izhotovleniia i primeneniia [Rock Destruction and Metal-Working Tools –Techniques and Technology of the Tool Manufacture and applications], Vol.19, 43–50 [in Ukrainian].

11. **Vynohradova, O.P.** (2015).Ruynuvannya girskih pored instrumentom z funktsionalnymi elementamy iz kompozitsiynyh almazovmisnyh materialiv[Destruction of rocks by the tool with functional elements from composite diamond-bearing materials].Candidate's thesis. Kyiv [in Ukrainian].

12. **Maistrenko, A.L., Shmegera, R.S., Manokhin, A.S.** (2019). Analiz produktiv znoshuvannia zviazky porodoruinivnoho elementu iz kompozytsiinoho almazovmisnoho materialu [Analysis of wear products of a rock-destroying element made of composite diamond-containing material].–Porodorazrushaiushchii i metalloobrabatyvaiushchii instrument - tekhnika i tekhnolohiia eho izhotovleniia i primeneniia [Rock Destruction and Metal-Working Tools - Techniques and Technology of the Tool Manufacture and applications],Vol. 22, pp. 93-102. [in Ukrainian].

13. **Shulzhenko, A.A., Ashkinazi, E.E., Sokolov, A.N.** (2009). Novyiultratverdyipolikristallicheskiikompozitsionnyi material [New ultrahard polycrystalline composite material]. - Porodorazrushaiushchii i metalloobrabatyvaiushchii instrument - tekhnika i tekhnolohiia eho izhotovleniia i primeneniia [Rock Destruction and Metal-Working Tools –Techniques and Technology of the Tool Manufacture and applications], Vol. 12, pp. 143–154. [in Russian].

14. **Safonova M.N., Petasyuk G.A. Syromyatnikova A.S.** (2013). Komp'yuterno-analiticheskiye metody diagnostiki ekspluatatsionnykh kharakteristik almaznykh poroshkov i kompozitsionnykh materialov na ikh osnove [Computer-analytical methods for diagnostics of operational characteristics of diamond powders and composite materials based on them].. - Novosibirsk: Iz-in SO RAN. [in Russian].

15. **Kirpichev M.V.** (1953). Teoriia podobiia [Similarity theory]. Moscow: USSR Academy of Sciences. [in Russian].

16. **Blinov G. A.** (1989). Almazosberegaiushchaia tekhnologiia bureniia [Diamond-saving drilling technology]. Lviv: Nedra. [in Russian].

17. **Vynohradova, O. P.** (2015). Kharakter vzaiemnoho ruinuvannia hirskoi porody ta almaznoho porodoruinivnoho instrumentu [The character of the mutual breaking of rocks and of diamond rock destruction tool]. Suchasni resursoenerhozberihaiuchi tekhnolohii hirnychoho vyrobnytstva. - Up-to-dateresource- andenergy- saving technologies in mining industry, issue 16(2),49-57 [in Ukrainian].